

# A Kinect-Based System for Balance Rehabilitation of Stroke Patients

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**SUMMARY** A low-cost prototypic Kinect-based rehabilitation system was developed for recovering balance capability of stroke patients. A total of 16 stroke patients were recruited to participate in the study. After excluding 3 patients who failed to finish all of the rehabilitation sessions, only the data of 13 patients were analyzed. The results exhibited a significant effect in recovering balance function of the patients after 3 weeks of balance training. Additionally, the questionnaire survey revealed that the designed system was perceived as effective and easy in operation.

**key words:** stroke, virtual reality, e-rehabilitation, balance shift

## 1. Introduction

It was reported that over a billion people have some forms of physical disability; among them, around 150 million people exhibit significant functioning difficulties of limbs [1]. Effective rehabilitation programs is essential for helping patients adjust their level of physical, psychological, and social functions to reach the best status, as well as reduce the length of hospital stay, readmission rate, and use of primary care resources. Hence, providing services to care for disabled people with motor function disorder is an important issue, which results in a great demand of computer-assisted devices for facilitating in-home rehabilitation.

Virtual reality (VR) offers a possible solution with realistic and enriching interactions, allowing the user to directly interact with a computer-simulated environment. Many VR systems have been developed specifically for rehabilitation to improve movement skills [2]. Devices designed with VR technology, such as Nintendo Wii and Microsoft Xbox Kinect, are becoming more affordable and accessible to be adopted as rehabilitation devices. Nintendo Wii used a con-

troller, which can be latched to the hand to make movements, while the Microsoft Xbox Kinect adopted a camera to track a player's movements, which are then reflected in game.

Most of the video games require the patient to hold a remote controller, which is difficult for some patients with serious motor injuries. After the prevalence of activity-promoting game systems, injuries associated with handheld controller overuse and repetitive motion were frequently found [3]–[8]. Compared to other video game platforms, Microsoft Kinect allows the users to interact with the machine through body gesture without needing any handheld controllers, which can significantly prevent the occurrence of musculoskeletal injuries. When used at home, a Kinect-based system can encourage increased use of the upper and lower extremities for older adults who generally lack of activities and movements as well as for patients who need to recover their body functions. The system presented here uses the Kinect to track the patient's body when playing a video game designed specifically for the rehabilitation of balance capability.

## 2. Balance Recovery Game System (BRGS)

Stroke patients often suffer from hemiparesis, which affects their balance ability and consequently their self-dependency and quality of life. Although effective therapies have reduced the mortality during the acute stages of stroke, patients still experience severe neurological disabilities. Deficits in motor control, abnormal synergistic organization of movements, muscle weakness, sensory deficits, and loss of range of motion can all reduce the quality of life in stroke patients.

### 2.1 Balance Shift Training

Virtual rehabilitation systems designed based on Kinect have been reported to provide benefits for lower limb rehabilitation in patients with Parkinson disease [9], physical rehabilitation in patients with motor disability [10], vocational task training in people with cognitive impairments [11], and upper extremity rehabilitation in stroke patients [12].

Balance shift training is a specialized form of physical therapy used to decrease primary symptoms of movement-related dizziness and imbalance through a customized "hands-on" approach. Additional symptoms addressed in

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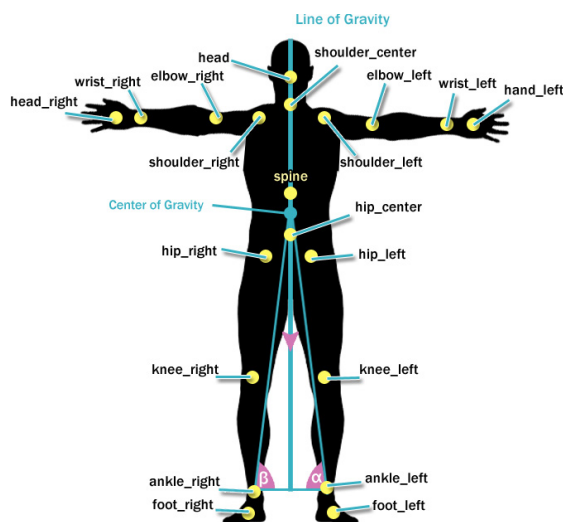
therapy may include decreased strength, loss of range-of-motion and muscle tension, anxiety, and fatigue. To skillfully control the center of gravity (CoG) is important for keeping one's body in balance. When someone stands in the anatomical position, the CoG is located anterior to the second sacral vertebra. The location of the CoG can be outside the human body during activities depending on the relationship of body segments. A person's CoG trajectory is useful to evaluate the dynamic stability during daily life activities such as walking and standing.

The balance training game was developed to achieve the following objectives: (1) to improve balance function and walking safety, (2) to facilitate visual motor control and tolerance of motion, (3) to increase levels of activity, and (4) to reduce frequency or risk of falls.

## 2.2 Video Game for Balance Rehabilitation

The Line of Gravity (LoG) is an imaginary vertical line passing through the CoG down to a point in the base of support. In the human body it passes from the vertex through the body of the second sacral vertebra down to a point between the feet when standing in the anatomical position. The gravitation pull acting at the CoG of any segments is along the LoG. As shown in Fig. 1, the CoG is located at the position which is slightly above the hip center along the LoG [13]. The CoG is detected from the Kinect infrared image [14].

To test the usefulness and effectiveness of the Kinect-based Virtual Rehabilitation System, the Balance Recovery game was used to train patients with stroke to recover their balance ability. Figure 2 (a) shows the user interface of the Balance Recovery System. The system was also designed for wheelchair users to support their balance improvement. It can detect balance shifts by processing Kinect skeleton frames. The function to train patients how to make correct balance shifts is also provided. The training can be di-

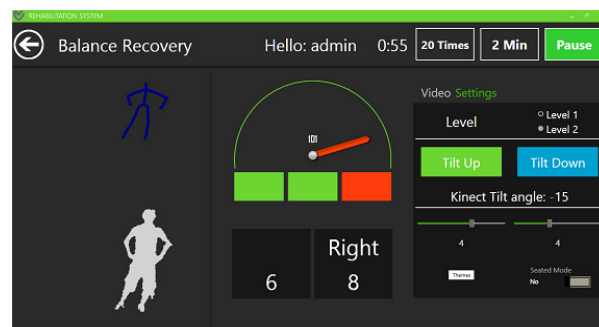


**Fig. 1** Illustration of joints detected and identified using codes provided by Microsoft Kinect SDK (modified from [14]).

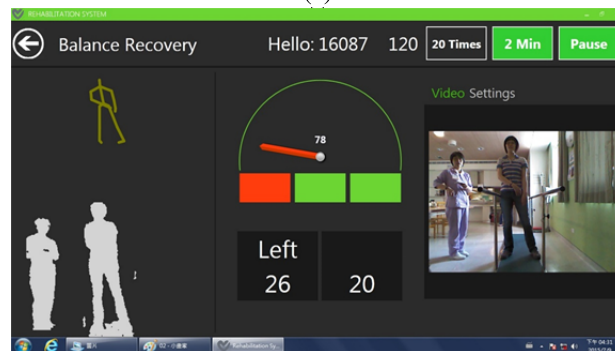
vided into easy (Level 1) and difficult (Level 2) modes by providing patients with different degrees of challenge. The default mode is Level 1 which asks the patient to stand in straight without bending the knees to do the balance shift. On the other hand, in Level 2, patients have to bend their knees before starting doing balance shifts. The software can automatically detect the patients' knee angles to determine whether they are standing straight or bending their knees. Real-time audio and visual feedbacks are also provided.

As shown in the figure, when the patient makes a shift, the gauge styled indicator shows which side the patient has shifted. When a correct shift has been identified, the system plays a sound and counts up by 1. Because some severe patients cannot make balance shifts with great angles, the system allows the therapist to adjust the minimum thresholds of left and right shift angles from the neutral position ( $90^\circ$ ) according to the patient's health status to determine whether a balance shift is counted as successful or not. The adjustable angle ranges from  $-10^\circ$  (right shift) to  $+10^\circ$  (left shift), making the shifting angle able to span from  $80^\circ$  (right shift) to  $100^\circ$  (left shift). This function is useful because some serious disabled patients can only start from a small shifting angle and gradually increase to a larger angle when one's health status has been improved.

As shown in Fig. 2 (b), the system can be used as a tool for assessing the performance of balance shifts by counting

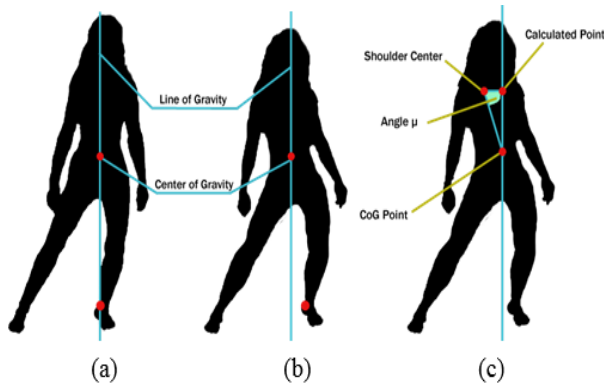


(a)



(b)

**Fig. 2** (a) The interface of the developed video-gaming system for training balance shift showing the function of video setting for assigning level of difficulty and desired tilted angles. (b) The system used as a tool for assessing the performance of weight shift by counting the number of bilateral weight shifts within 2 minutes.



**Fig. 3** Illustration of (a) correct and (b) incorrect balance weight shifts during Tai Chi exercise. (c) Calculation of the tilted shoulder angle ( $\mu$ ) in an incorrect balance weight shift (modified from [15]).

the number of bilateral weight shifts within 2 minutes. As presented in this figure, the patient could do 26 left shifts and 20 right shifts under the set level.

### 2.3 Calculation of Balance Shift Angle

The system code provided by Kinect SDK calculates distance between 2 points and individual angles of a triangle using Pythagorean Theorem and law of cosines, respectively.

As shown in Fig. 1, the triangle formed by CoG, ankle\_left joint, and ankle\_right joint is divided by LoG into 2 triangles which are useful for the calculation of left and right balance shift angles,  $\alpha$  and  $\beta$ , respectively. Figure 3 illustrates examples of correct and incorrect balance weight shifts during the Cloud Hands, which is a basic movement of Tai Chi exercise [15]. Please refer to [16] for detailed procedure in detecting the correct balance shift.

### 2.4 Subjects and Statistical Analysis

A total of 16 patients (8 males and 8 females) were recruited to participate in the study. After the stroke, they have difficulties in balancing their limbs because of neurologic injury. All the tests were conducted at the Department of Rehabilitation, Taichung Hospital, Ministry of Health and Welfare. Each participant underwent 10 sessions of treatments within 3 weeks, each lasting for 5–10 minutes to finish 20 left and 20 right balance weight shifts. Among them, data of 3 patients were excluded because of failing to finish all of the treatment sessions, only the data of 13 patients (6 males and 7 females) were analyzed. Table 1 shows the demographic information of the studied participants.

In order to assess the effectiveness of the developed BRGS, patient's activity during rehabilitation was logged into the database for later analysis. A statistic software package (SPSS 18) was used for descriptive and inferential statistical analyses. The outcomes were tested with paired-sample *t*-test and one-sample *t*-test with a defined significance level of  $p < 0.05$ .

**Table 1** Demographic information of the studied patients (N = 13)

Variable	Gender (Male/Female)	Age in year (SD)	Limb weakness (Left/Right)	Stroke type (Hemorr/Infarct)
Value	6/7	59.3 (12.6)	5/8	6/7

## 3. Assessment

All the participants were assessed by the Berg Balance Scale (BBS), Biodex Balance test, Get up and Go test, and Balance Recovery Game System (BRGS) before (initial assessment) and after (final assessment) balance rehabilitation. The user satisfaction was also surveyed using a questionnaire.

### 3.1 Biodex Balance Machine

Biodex balance system is a widely used device for quantifying dynamic balance performance. It evaluates the ability to maintain equilibrium while standing on a movable support surface with varying degrees of vibration and instability [13]. Establishing reliability is necessary for either situation when using Biodex Balance System to discriminate balance among individuals or using it to evaluate balance changes over time following an intervention program. In this study, overall stability index (OASI) was used to examine the static balance ability of the patients. The OSAI includes anteroposterior stability index (APSI) and mediolateral stability index (MLSI), which indicate the ability of anteroposterior mediolateral directions, respectively. A lower score on these indices means better balance ability achieved.

### 3.2 Berg Balance Scale

The Berg Balance Scale (BBS) is generally considered as the gold standard of functional balance tests and is widely used for clinical test of a person's static and dynamic balance abilities [17]. It was developed to measure balance among older people with impairment in balance function by assessing the performance of functional tasks.

The test takes around 15–20 minutes and comprises a set of 14 simple balance-related tasks, ranging from standing up from a sitting position to standing on one foot. The degree of success in achieving each task is given a score ranging from zero (unable) to four (independent) with the final measure calculated by summing all the scores. The BBS has been recently identified as the most commonly used assessment tool across the continuum of stroke rehabilitation. Higher score indicates good balance ability.

### 3.3 Get up and Go Test

The test calculates the time that a person who rises from a chair, walks three metres long, turns around, walks back to the chair, and sits down. During the test, the person could use any assistnt aids [18]. Smaller time taken means good

**Table 2** Comparisons of balance capability for patients before and after rehabilitation

Index	Initial Test	Final Test	Mean Differ	t-value	p-value
Biodex OASI	0.74 (0.53)	0.58 (0.13)	-0.163 (0.486)	1.116	0.291
APSI	0.50 (0.25)	0.40 (0.10)	-0.109 (0.230)	1.573	0.147
MLSI	0.49 (0.48)	0.34 (0.12)	-0.145 (0.436)	1.105	0.295
Get Up & Go	29.32 (16.16)	13.81 (7.80)	-15.52 (20.1)	2.784	0.017*
BBS	45.54 (10.46)	32.31 (25.56)	-13.23 (21.73)	2.196	0.049*
Left Shift Cnt	14.77 (5.62)	36.08 (8.63)	21.31 (9.02)	8.515	<0.001**
Right Shift Cnt	17.15 (10.29)	35.54 (8.86)	18.39 (12.68)	5.228	<0.001**

Note: Student's *t*-test with \* $p < 0.05$ , \*\* $p < 0.01$ , and \*\*\* $p < 0.001$

mobility and balance function.

### 3.4 Kinect Balance Recovery Game System

The participants were asked to stand in shoulder-width stance on a fall-protection platform by keeping their eyes open to conduct balance shifts to determine their balance ability. The patient was asked to do exercise with the developed game for 2 minutes with the number of movements to the right and left sides (Right Shift Count and Left Shift Count) being recorded. Balance shifting gesture was adopted from ancient Chinese Taichi movements, which emphasize on weight-shifting, postural alignment, and coordinated movement skills. The experimental setup is equipped with a 32-inch monitor, hand-hold supporting rail, computer, and the Kinect device. Usage attitudes have been assessed using the questionnaire after the subjects have completed using the Balance Recovery system.

## 4. Experimental Results

Table 2 compares the treatment outcomes of the initial and final tests using paired *t*-test. As shown in the table, Get Up and Go scale, BBS sum, Left Shift Count, and Right Shift Count exhibit significant improvement ( $p < 0.05$ ) after rehabilitation with BRGS. On the other hand, no significant improvement ( $p > 0.05$ ) was observed for OASI, APSI and MLSI of the Biodex assessment. The patients got better Biodex scores after BRGS intervention although no significant improvement was observed. The Overall Stability Index was calculated based on both APSI and MLSI.

Table 3 shows the survey of usage attitudes after the patients have finished the rehabilitation using the BRGS. The results were compared with the neutral value (3) and tested with one-sample *t*-test with significance defined as  $p < 0.05$ . As indicated in the table, the patients expressed that the BRGS is interesting ( $p < 0.05$ ) and easy to control by hand ( $p < 0.05$ ); the GUI of BRGS is easy to use ( $p < 0.001$ ); the feedback message is clear and easy to understand ( $p < 0.05$ ); the rehabilitation is effective ( $p < 0.01$ ); the patients feel comfortable with the game ( $p < 0.01$ ); and they can immerse in the virtual environment ( $p < 0.01$ ). However, they don't agree that BRGS can simulate the realistic environment ( $p > 0.05$ ).

**Table 3** Assessment of user attitude

Question	Mean (SD)	t-value	p-value
I think playing the BRGS games is interesting	3.88 (1.03)	2.42	0.046*
I think I can immerse in the designed environment when playing the BRGS games	4.13 (0.83)	3.81	0.007**
I think treatments with the BRGS games is effective	4.25 (0.70)	5.00	0.002**
I think the BRGS games can be easily controlled by hands	4.25 (1.03)	3.41	0.011*
I think the BRGS games can simulate the realistic environment.	3.25 (0.88)	0.79	0.451
I can understand the messages feedback by the BRGS games	4.13 (0.99)	3.21	0.015*
I am comfortable with the BRGS games	4.38 (0.74)	5.22	<0.001***
I think the BRGS games are easy to operate	4.50 (0.54)	7.93	<0.001***

Note: One-sample *t*-test with \* $p < 0.05$ , \*\* $p < 0.01$ , and \*\*\* $p < 0.001$

## 5. Discussions and Conclusions

The intervention based on video-tailored physical activity was reported to be feasible in terms of user preference [19]. It was shown that almost all the participants in the focus group agreed with the concept of video-tailor intervention, and around 36% of the surveyed participant favored a video-based over a text-based physical activity intervention. When designing a video, most surveyed participants preferred someone similar to themselves to present the personal physical activity, and the video should be personalized and not last longer than 5 minutes [20]. In this study, during each training session, the stroke patients were asked to finish 20 left and 20 right balance shifts within 5–10 minutes, which is a little longer than 5 minutes, because of impaired walking and balance functions that greatly degraded their moving capability.

After the prevalence of activity-promoting game systems, such as Nintendo Wii and Sony PlayStation, injuries associated with handheld controller overuse and repetitive motion were frequently found. Spark et al. [9] categorized Wii-related injuries into 4 different types: tendinopathy, bursitis, enthesitis, and epicondylitis. According to an investigation of self-reported cases, 9 types of injuries have been identified; among them, hand lacerations related to overuse or incorrect use of handheld controller were the most commonly observed injury [7]. Other injuries, such as Tendinitis occurred in the thumb [4], [5] and Wii-itis in the shoulder and upper arm [3], [8] related to intensive use or improper use of handheld controller were also reported in the literature.



The entertainment video games developed under Wii Fit gaming system with Balance Board have been reported to be effective for training balance function and assessing balance recovery. However, it was argued that these games were designed for healthy people to experience virtual exercise, which is different from the therapeutic scenarios required for patients with stroke, brain injury, or other disabilities [21]. Moreover, only center of pressure was detected and monitored by the games developed based on the Wii Balance Board. It was reported that exercises involving both trunk muscles and postural control were shown to have the benefits in increasing balance performance [22]. For example, Tai Chi exercise has been demonstrated to be effective in increasing strength of core muscles and improving ability of posture control [23]. In contrast to the Wii Balance Board, in addition to measuring CoG, our Kinect-based gaming system developed based on Tai Chi exercise also emphasized on training patients to conduct balance weight shifts with correct posture. It has been shown to be beneficial in the recovery of balance function for stroke patients.

Recently, a virtual reality rehabilitation system based on Microsoft Kinect has been designed to provide upper-body interaction for patients with cerebral palsy whose ranges of movement are generally limited [24]. The prototypic system provided the functions for adjusting control/display ratio, defined as the ratio of the amplitude of the patient's hand movement to the amplitude of the avatar's movement, which is useful for setting up the virtual environments based on limited ranges of movement of patients. To obtain real hand movement, upper-body joints including left/right hands, wrists, elbows, and shoulders were detected. In comparison, our system detected joints of left/right ankles, knees, hips, and shoulders for calculating balance shift angle and tilted shoulder angle.

Sedentary activities may risk people in overconsumption of food, resulting in the acquisition of obesities, cardiovascular diseases, and cancers. Compared with sedentary individuals, people conducting regular low-volume physical activities (92 min/week in average) can reduce the risk of all-cause mortality of 14% and increase the life expectancy of 3 years [25]. It was also reported that playing bowling, tennis, and boxing of the Wii Sports consumed at least 50% more energy than sedentary gaming for adolescents [26]. Compared to a traditional sedentary video game, the heart rate, oxygen uptake, and energy expenditure of schoolchildren were significantly higher for 2 Kinect activity-promoting video games [27].

This study presented a rehabilitation system based on markerless interaction in a virtual reality environment, which is intended to be used for balance rehabilitation inspected by healthcare professionals in hospitals, and can also be used for in-home rehabilitation. The virtual training was shown to have a significant effect on recovering the balance capability of patients. Adopting the VR rehabilitation system at home is more flexible, cheap, and convenient for patients needing more frequent and repetitive exercises.

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